# BEAM-BEAM STUDIES AT RHIC*

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## 1 RHIC BEAM-BEAM COLLISIONS

In this talk we discuss possible beam-beam studies that could be done at the RHIC collider. These studies are not only interesting for the understanding of the RHIC operational limits, but also for the operation of future hadron colliders, like the LHC. These studies could verify predictions of analytical calculations and beam-beam simulations, especially in the strong-strong regime.

The RHIC collider is suited for beam-beam experiments, both in the strong-weak and the strong-strong regime. Tab. 1 shows the basic parameters for gold and proton operation at injection and storage energy. The collider consists of two rings which intersect at six interaction points, where equal species collide head-on. Outside the interaction regions the beams are separated in the horizontal plane. Separation is achieved through DX and D0 magnets (see Fig. 1).

During the first years of operation, RHIC will use 60 bunches in each ring. Future upgrade scenarios include up to 360 bunches per ring. With 60 bunches there is enough longitudinal spacing between consecutive bunched so that no parasitic beam-beam collisions occur in the interaction regions. With the increase of the number of bunches to 180 or more a crossing angle up to 1.3 mrad would be required to reduce the effects of parasitic collisions [1].

With the moderate values of the beam-beam parameter $\xi$ we expect that the beam-beam interaction would not be a dominant effect, especially for gold-gold collisions. On the other hand, beam-beam effects should be observable.

## 2 DIAGNOSTIC AND CONTROL TOOLS

To carry out studies, a set of tools and instruments is necessary for the control and measurement of beam parameters. The basic manipulation required for beam-beam studies is to bring the two beams in and out of collision. This can be done longitudinally and transversely. The transverse orbit control should also provide the ability for a precise change of the beam crossing angle at the interaction point.

In RHIC a crossing angle up to 1.3 mrad can be created through the DX and D0 magnets. Precise interaction point orbit separation and angle control is done by using orbit bumps of 4 interaction region dipole correctors. These horizontal and vertical interaction region bumps will be used to maximize the collider luminosity. The beam-beam separation at the interaction point can be performed with a step size of 0.02mm. The maximum beam separation that can be obtained through bumps is 9.4mm at the top energy.

The orbit position and angle at the RHIC interaction points can be extracted using the measured beam positions at the DX beam position monitors (see Fig. 1). These dual-direction, dual-plane BPMs are located at both sides of the interaction points. The relative precision of BPM measurements reaches 0.01mm.

The following list presents other beam instrumentation that is useful for beam-beam studies at RHIC:

- A tune meter and Schottky system for the measurement of betatron tunes, tune spread and other beam oscillation modes.
- A tune meter kicker to excite bunches with a single kick or multiple kicks.
- A Ionization Profile Monitors (IPM) for the measurement of the transverse beam profiles. When fully commissioned the IPM can measure individual bunches turn-by-turn.
- A beam current transformer to measure the total beam current and a wall current monitor to measure the current per bunch.
- A Zero Degree Calorimeter for luminosity measurements and optimization.

## 3 POSSIBLE BEAM-BEAM EXPERIMENTS AND STUDIES

The following list of the beam-beam studies is proposed to be carried out at RHIC. Some of them might be important to better understand and improve the RHIC operation while others are of a more theoretical interest.

### *Weak-strong beam-beam studies:*

- The observation of diffusion caused by the beam-beam interaction. This can be done using the beam size measurements from the ionization profile monitor. In gold operation, this effect will be difficult to detect due to intra-beam scattering.
- The measurement of beam-beam caused tune spread and tune dependence on betatron amplitude Q(J). This should follow measurements of amplitude dependent tune shift from nonlinear magnetic effects.

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Table 1: Basic RHIC parameters.

| | Au injection | Au top | p injection | p top |
|---|---|---|---|---|
| Z | 79 | 79 | 1 | 1 |
| A | 197 | 197 | 1 | 1 |
| $\beta^*$ (m) | 10 | 1 | 10 | 1 |
| $Q_{x,y}$ | 29.18/28.19 | 29.18/28.19 | 29.18/28.19 | 29.18/28.19 |
| $N_b$ | $10^9$ | $10^9$ | $10^{11}$ | $10^{11}$ |
| $\gamma$ | 12.6 | 108 | 31.2 | 268 |
| $\sigma_l$ (m) | 0.88 | 0.17 | 0.5 | 0.09 |
| $\Delta p/p\,(10^{-3})$ | 0.74 | 0.64 | 0.51 | 0.34 |
| $95\%\epsilon_N$ ($\pi$mm-mrad) | 10 | 10-40 | 20 | 20-30 |
| $\sigma^*$ (mm) | 1.15 | 0.124 | 1.07 | 0.112 |
| $\xi$ | 0.0012 | 0.0012 | 0.0037 | 0.0037 |

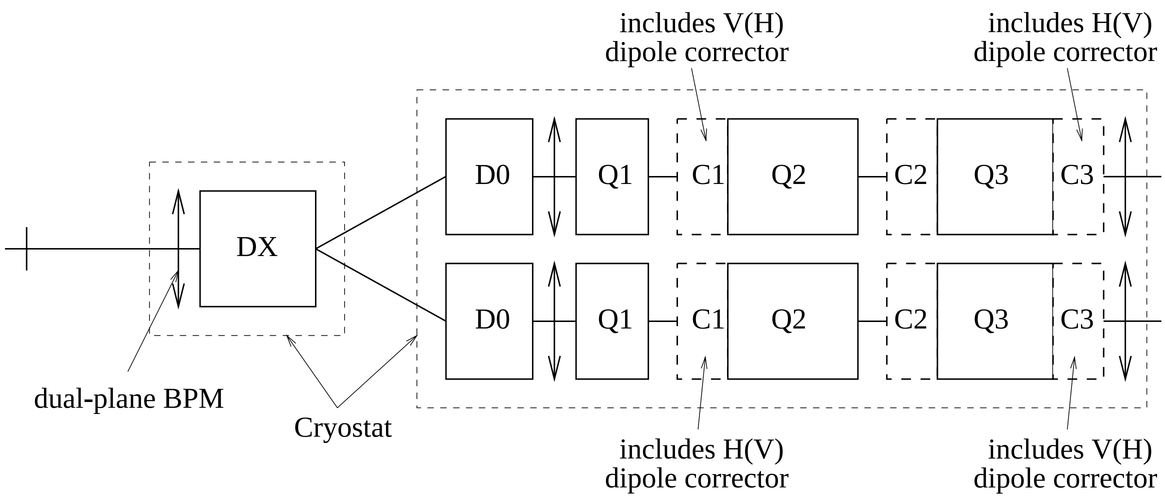


Figure 1: Half side of an RHIC interaction region from the top. DX separates the beams initially and D0 further. Q1,Q2,Q3 are quadrupoles, C1,C2,C3 are multi-layer corrector packages.

- Beam-beam effects as a function of the betatron tunes. Horizontal and vertical betatron tunes can be scanned easily.

- The measurement of the effect of parasitic beam collisions. This can be done with beam separation at 1 or 2 interaction points with the help of the orbit separation bumps [2]. Up to 10$\sigma$ separation is required to approximate the conditions of the LHC.

- The study of synchro-betatron resonances caused by the crossing angle. The effect should be noticeable when the crossing angle $\alpha$ is of the order of the ratio of the transverse and longitudinal beam sizes. Required crossing angles are:
  $\alpha/2 = 1.2$mrad (storage RF system, top energy)
  $\alpha/2 = 0.6$mrad (acceleration RF system, injection energy)
  The second option requires the smaller crossing angle that can be created by DX,D0 magnet adjustment.

- The studies of the beam-beam effect with unequal beam emmitances to verify SPS results.

- The observation of whether and how beam-beam collisions affect the beam polarization. This can be done with intense polarized proton beam at injection.

### *Strong-strong beam-beam studies:*

- The observation of coherent beam-beam mode tunes. The tune meter kicker can be used to excite coherent beam motion. The Schottky monitor could detect coherent modes. These studies probably require the corresponding betatron tunes in two ring to be equal within 0.002.

- In case the coherent modes are observed, they could be used to optimize beam-beam head-on collisions [3].

- The measurement of beam-beam coherent modes as a function of the betatron tune split between the two rings. This could test the idea that the coherent motion would be decoupled between two beams with an increase of the tune split [4].

- The study of the coherent modes dependence on the beam separation (long-range interactions) modes.
- The study of the closed orbit distortion by long range beam-beam interactions.

The last two items might have a special interest for the LHC project where the parasitic long-range beam-beam interaction provides the considerable contribution to beam-beam effects.

Some of the studies can be done parasitically at the polarized proton run. With the beam of protons containing many bunches in one ring and few bunches (1-3 bunches) in another ring, only few bunches of polarized beam would be affected by beam-beam interactions.

## 4 SUMMARY

- We expect that the RHIC nominal operation would not be strongly affected by beam-beam effects, especially in gold-gold collisions. This need to be confirmed by operational experience.
- RHIC is equipped with a variety of diagnostic and control tools that are sufficient for effective beam-beam studies and experiments.
- We are open to and encourage collaboration in this area.

## 5 REFERENCES

[1] S. Peggs, RHIC/AP/169

[2] W. Fischer, F. Zimmerman, RHIC/AP/179

[3] Suggested and considered for RHIC by W. MacKay and A. Drees

[4] A. Hoffman, LHC Beam-Beam Workshop, 1999.